345021

CASE FILE COPY

TECHNICAL MEMORANDUMS

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

No. 565

DEVELOPMENT OF THE JUNKERS-DIESEL AIRCRAFT ENGINE

By Dr. Gasterstädt

From Automobiltechnische Zeitschrift
January 10 and 20, 1930

Reproduced by
NATIONAL TECHNICAL
INFORMATION SERVICE
US Department of Commerce
Springfield, VA. 22151

PRICES SUBJECT TO CHANGE

Washington
May, 1930

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS.

TECHNICAL MEMORANDUM NO. 565.

DEVELOPMENT OF THE JUNKERS-DIESEL AIRCRAFT ENGINE.*

By Dr. Gasterstädt.

The realization of both high speed and light weight in the construction of a Diesel engine is fundamentally difficult.

In the first place, complete combustion in the cylinder of a Diesel engine presents very great difficulties because of the requisite perfect atomization and distribution of the fuel during the relatively short time available at high speeds (about 1/10 of that of the carburetor engine).

In the second place, the Diesel engine works with higher compression and combustion pressures than the carburetor engine, so that the driving parts are heavier for a cylinder of given dimensions, which makes it difficult to use light construction.

The working process of the Junkers engine (Fig. 1) has resulted from a series of attempts to attain high performance and to control the necessarily rapid and complete combustion at extremely high speeds.

It was resolved as a matter of principle to change from the four-stroke cycle to the two-stroke cycle. This is not feasible in a carburetor aircraft-engine on account of unsolved difficulties in scavenging and control.

*"Die Entwicklung der Junkers-Diesel-Flugmotoren," an abstract of a paper read before the Wissenschaftliche Gesellschaft für Luftfahrt. From Automobiltechnische Zeitschrift, January 10 and 20, 1930.

As is well known, in each cylinder of this engine there are two pistons moving in opposite directions. The scavenge piston controls the admission of fresh air and the exhaust piston controls the exit of the combustion gases by uncovering the proper ports in the cylinder wall.

For high speed the effect of the scavenging air flow is especially important to accomplish the essential thorough mixing of air and fuel. An active spiral motion is imparted to the scavenging air stream by the diagonal position of the scavenge slots. In the aviation engine these slots resolve themselves into a great number of scavenge ports through which the internal turbulence of the air stream is sensibly increased (Fig. 1, left).

This whirling motion persists in the straight cylindrical clearance space throughout the compression and working strokes (Fig. 1, middle).

Into this rotating disk of air there is injected at the end of the compression stroke, the fuel as well atomized and distributed as possible. The injection is accomplished without air by means of hydraulic pumps which force the fuel directly into the combustion chamber through open nozzles. The distribution of the fuel through several nozzles is of particular importance for high-speed operation. So much for the main points of the working process. Therefrom follows the mechanical construction of the engine (Fig. 2).

The adaptation to high-speed operation was accomplished by means of a basic rearrangement of the driving mechanism. Figure 2 shows at the left the operating mechanism of a single-shaft, stationary engine and at the right the two-shaft, high-speed engine. By the latter arrangement the long connecting rods are eliminated, so that the weight of the moving parts and the size of the engine are reduced to a minimum.

All of the fundamental steps leading to the Junkers aviation engine are characterized by the transition (1) to the two-shaft arrangement, (2) to airless injection, and (3) to spiral scavenging. It is astonishing to recollect that these characteristics were already incorporated in our 1915 engine.

The experimental data of 1914 show that the superiority of spiral scavenging was well established on the basis of engine tests, so that the fuel consumption was reduced from 175 to 159 grams (.386 to .350 pound) per horsepower per hour.

Figure 3 shows the engine, 1916 model, in which the later development of the rotary blower appears instead of the earlier piston air pump.

One must visualize the status of the Diesel engine during 1923 and 1924 to appreciate the gap that was still to be bridged. At that time, while carburetor engines of 400-500 hp, weighing 1 kg/hp (2.2 lb./hp) had already proved practical, the basis of the Junkers engine was the stationary HK engine, weighing about 30 kg/hp (66 lb./hp) (Fig. 4). The table shows what an increase

in performance followed the adoption of the heavy-oil aircraft engine. The automobile engine is also shown for comparison. The data are based on endurance tests for all three engines.

The first line gives the horsepower per liter of stroke volume or piston displacement. This shows the fundamental superiority of the two-stroke cycle, since this value of 21 hp per liter already reaches and even excels the best carburetor engines and the piston speed is no lower. Line three gives the weight-power ratio in kilograms per horsepower. The weight was reduced to 1/20 of that of the stationary engine.

The steps taken in 1924 and 1925 were not applied to an experimental engine of small or medium power but, on the contrary, to a 700-800 hp oil engine, the "FO 3."

The most important further constructive step was the change to an integral engine-and-drive casting (Fig. 5). This change resulted from considerations of the strength and rigidity of a complete connection between the cylinders and the driving gear.

The large casing which unites 5 cylinders into one block, imposes great demands upon the technique of casting light metals. It must be a very strong, bubble-free, and flawless casting which is also corrosion-proof from the flow of water through it.

From the very beginning, the material chosen was silumin, a special alloy developed at the suggestion of Junkers. This is remarkably easy to cast and has good strength, density, and

corrosion resistance with a specific gravity of only 2.65.

The first "FO 3" engine came to the test stand for trial in the middle of 1926. The first tests promised great advantages for aircraft.

Three months later this engine reached a peak performance of 830 b.hp at 1200 r.p.m. with a mean effective pressure of 8.3 atmospheres during a half-hour run. The empty weight of the complete engine was about 930 kg (2050 lb.). The duration of the run may appear short but the results were important, in that they showed that the goal could be reached by the path upon which a start had been made. The next problem was to design the parts of the engine so they would be thoroughly capable of withstanding the working stresses. For every new engine has its defects, and an 800 hp aviation engine at this stage of its development may be very troublesome.

In the "FO 3" engine a certain fundamental defect in the 5-cylinder type evidenced quite an undesirable effect in the imperfect balancing of the centrifugal moments. On this account a change was made about a year later to a 6-cylinder engine, the present "SL 1," whose dimensions were proportional but somewhat smaller, corresponding to a cylinder bore of 120 mm (4.72 in.) instead of 140 mm (5.51 in.) in the 5-cylinder engine.

While this engine was being built, numerous experiments were made on the separate problems of the working process and of light construction for which two special single-cylinder experimental engines were used (Fig. 6).

In the following, the working process is first investigated more fully. Fresh air must be supplied to the cylinders not only with extreme rapidity, but with a minimum expenditure of energy. This requires short, large pipes between the blower and the cylinders and, above all, control ports with large cross sections. In the two-stroke cycle these can be enlarged at will over a wide range, but only at the expense of the volume of fresh air contained in the cylinder. In the interest of the greatest possible cylinder performance, one endeavors therefore to obtain the greatest possible charging volume with the most favorable scavenging.

Figure 7 shows the indicator diagram of the two-stroke-cycle engine, i.e., the pressure plotted against the displacement. This working process is controlled by the simultaneous motion of both pistons. Thorough expansion of the combustion gases through properly timed opening of the exhaust ports before the scavenging piston opens the fresh-air inlet is especially important for high-speed engines. The two-shaft engine possesses a very practical and simple means of enlarging the exhaust opening, in that the crank is adjusted to run a little ahead on the exhaust side. In this manner the outlet ports not only open earlier, but the scavenging ports close correspondingly later, even after the closing of the exhaust ports, and thus fill the cylinder with fresh air at the scavenging pressure.

In order to give an illustration of the proportions of the

control members in a high-speed engine, a comparison is made (Fig. 8) between the characteristics of the well-known four-stroke-cycle carburetor engine, Junkers "L 5" and the oil engine. All values in this figure are computed on the basis of equal piston displacement and r.p.m.

The amount of port opening of both engines is plotted in the diagram against the time, i.e., the crank angle. Whereas in the four-stroke cycle, 440 degrees of crank angle are available for exhaust and intake, only 150 degrees are available in the two-stroke cycle (about 1/3). Therefore, the sectional area of the port opening is several times greater in the two-stroke cycle and the opening and closing take place much more rapidly. One can clearly recognize, in the two-stroke cycle, the influence of the advanced angle on the displacement of the exhaust and scavenging processes.

The product of control cross-sectional area by the time, i.e., the area in the control diagram, gives a measure of the charging of the cylinder. These values are given in horizontal bars in the next row, separated for intake and exhaust (Fig. 8). The values give sufficient information concerning the proportions, above all, the large exhaust cross-sectional area of the two-stroke cycle.

The volume ratios between the control points (at the bottom in the figure) refer to equal piston displacements. It will be seen that, in the two-stroke cycle, for the sake of the best

scavenging, a lower volumetric efficiency (72% against 92% in the four-stroke cycle) must be taken.

We must not forget, however, that, in the two-stroke cycle, these quantities must be multiplied by 2 in determining the cylinder performance for a definite mean pressure. In our particular case the two-stroke cycle gives 55% greater performance on the basis of volumetric efficiency.

In the one-cylinder experimental engine, only the size of the charging manifold, the advance angle of the crank shaft of the exhaust pistons, the inclination of the scavenging channels and the scavenging pressure were systematically altered, and the influence on fuel consumption and maximum attainable performance were observed and measured. Figure 9 shows the effect of varying the rotation of the scavenging air on the combustion simply by varying the angle of incidence; a gain of 10% in performance is obtained.

By the proper dimensioning of the admission ports and correct conduction of air, it was possible to lower the scavenging pressure to 0.2 atmosphere at full power without impairing the combustion. Hand in hand with the expedients taken to improve the admission of air went the improvement of fuel injection.

From a physical standpoint the task consists in bringing each fuel particle into contact with the requisite amount of combustion air in the shortest possible time. The difficulty of this lies in the shortness of the time available. In an oil en-

gine operating at 1500 r.p.m., this is about 0.001 second. In this short interval the entire process of injection and atomization controlled by the pump takes place and is repeated 25 times in each cylinder in a single second. The means for controlling this process are as follows:

The Junkers nozzle liberates the fuel jet in the shape of a fan of about 120 degrees angle. Figure 10 shows this fan shape, which well suits the flat combustion chamber. Its regularity can be observed by injection into quiet air.

The distribution becomes more perfect when several nozzles are arranged around the periphery of the chamber (Fig. 11). There is also the possibility of making the distribution more effective by inclining or crossing the fan planes.

The degree of atomization (i.e., the fineness of the drops) plays an important part in the completeness of the combustion. If the atomization is too coarse, the individual particles will burn too slowly, while if the atomization is carried too far the fuel jet will lose its kinetic energy and fail to penetrate far enough into the combustion chamber. For a given shape of nozzle the degree of atomization is determined by the size of the nozzle aperture. The smaller the opening, the finer is the degree of atomization obtained.

The question now arising is: What injection pressures will give a high degree of atomization in a short interval of time? The injection pressure determines essentially the construction-

al details of the pump, nozzles, and connections, and the reliability and lasting qualities of the injection system.

In general, it can be said that the smaller the quantity of fuel and the shorter the injection tube, the more favorable are the pressure conditions for a given short injection time. From this standpoint the aviation oil engine has reached, in progressive stages, a considerable degree of perfection.

The division of the fuel quantity for each cylinder among four nozzles and two pumps (Fig. 12) which are located near the injection valves, results in small pumps and short injection tubes. The shortness of the nozzle connections minimizes not only the resistance of the tubes, but avoids any after-dripping of the open nozzles, as may easily occur with long tubes through oscillations of the fuel column.

The injection pressure for this pump arrangement, measured in the injection tube is plotted in Figure 13 against the r.p.m. for different quantities of fuel. Since, in normal operation of the engine, two pumps always deliver fuel to one cylinder, each pump does not deliver full fuel quantity even at maximum engine performance. The pressures thus obtained, as shown in the diagram, are therefore not particularly high. Higher values are often encountered in stationary engines with long fuel pipes.

The results of all provisions taken to improve the scavenging and injection process appear in the attainable engine performance and low fuel consumption. From this standpoint the

aviation oil engine is not behind the best stationary Diesel engine, a result which was not originally expected of high-speed engines, but which will be experimentally proved further on. The effect of speed (Fig. 14) can be attributed first of all to the effect it has on the scavenging pressure and the scavenging work.

An interesting chapter is the constructional development of the fuel pump which has made possible the aircraft Diesel engine. With increasing adaptation to high speed and light-weight construction, it diverges more and more from the generally accepted standards of pump construction with its many and various elements of control, regulation, drive, packing, and lubrication.

The requirements of such a pump are: accurate delivery of the smallest quantities of fuel at the highest injection pressure, therewith absolute internal and external tightness (i.e., fuel must not leak out nor air get in); very rapid motion of its parts (duration of delivery stroke being only 0.001 sec.); minimum size and weight of the entire pump; good adjustability and controllability.

The means through which these requirements are realized are:

1. Greatest simplification of construction (smallest number of ports and least complicated construction forms);

2. Increasing precision in production by means of fine machinery;

3. Development of special materials of highest compressive strength and resistance to wear.

Figure 15 shows the fuel pump in section and in its position relative to the cylinder.

The pump plunger, in the absence of all mechanically controlled valves, governing slide valves and stuffing boxes, performs all the functions of control and regulation solely through its motion in the cylinder. There remain only one or more check valves of the simplest form in the pressure pipe to the open nozzle. The regulation of the quantity of fuel is accomplished by merely turning the plunger which is provided with an oblique regulating groove (or distributing edge). All the pumps on one side of the cylinder are connected by a control rod which can be regulated by the operator. The engine can function with one row of pumps shut off.

The objections, which even to-day in the experimental stage of aeronautics are often sharply expressed against the turboblower, are made mainly on account of the performance at low revolution speeds. It is well known that the pressure generated by a turboblower decreases as the square of the speed, so that by the direct coupling of the blower to the engine, extremely undesirable accelerations and unpermissible starting characteristics could be predicted. It was thereby overlooked that not

only the scavenging pressure, but also the resistance to the motion of the scavenging air decreased as the square of the r.p.m.

Structural considerations necessitated scavenging pressures of about 0.2 atm. in each stage. This corresponded to a peripheral speed of the rotor of about 200 m/s (656 ft./sec.), which produces a high centrifugal force in the rotor due to its own weight. The material of the rotor must therefore possess the highest possible ratio of elastic limit or yield point to specific weight. On close examination it has been found that in this respect the characteristics of duralumin and elektron very closely approach those of the best steel. From the standpoint of minimum weight and good machinability, duralumin was therefore selected for the construction of the rotor.

The form of the rotor was considerably improved during the course of the tests. While at first the rotors consisted of blades riveted to the lateral plates (Fig. 16), extremely light and strong wheel forms were subsequently worked out of a single piece of metal.

The performance characteristics obtained with this single-stage blower were satisfactory in every respect, as shown in the curves (Fig. 17). The power curve is plotted in addition to the characteristic curves and the efficiency curve.

The development work on the turboblower was continued and has very recently shown the possibility of a considerably broader application of the single-stage high-speed blower.

The drive of the scavenging blower required special attention. On account of its high speed, a stepping up of 1 to 7 with respect to the engine, the rotor is a very effective rotating mass, the acceleration of which requires large forces. For this reason a coupling was inserted between the engine shaft and the blower shaft, which operated as a friction coupling to prevent excessive accelerations in starting and sudden changes in the revolution speed. It operates also as an elastic coupling through the introduction of suitable springs to avoid dangerous torsional vibrations between the rotating part of the engine and the blower rotor within the operating rotational-speed range. This coupling is built directly into the starting wheel on the crank shaft.

The question of temperature control and of heat transmission through the engine, has been a difficult problem for the Diesel aircraft engine and the object of extensive research. Adaptation of the construction to the best heat elimination was required.

During the working stroke the heat is first imparted to the piston and cylinder walls, from which it must be carried away by the cooling water.

For the purpose of investigating the temperature of the moving piston, the single-cylinder experimental engine mentioned at the beginning was equipped with thermocouples for temperature measurements. This enabled the simultaneous continuous observa-

tion of temperature variations at about ten test points on the piston up to speeds of 1200 r.p.m. (Fig. 18). Constantan-steel elements were used and by means of an ingenious device only the extremely flexible steel wires had to be led over movable guides to the fixed measuring device on the outside.

The diagram shows, as an example of measurement, the investigation of a cast-iron piston, as it was experimentally reconstructed, in the course of its development from the piston of a stationary Junkers engine, for the heavy-oil aircraft engine. The exceptionally thin-walled, reinforced piston was cooled by splashing oil, which moved to and fro in the upper closed space of the piston head and removed the heat from the top of the piston. These experiments were later carried out with light-metal pistons and furnished the basis for their development.

The experiments on pistons were supplemented by simultaneous temperature measurements on the cylinder walls.

We will now consider the construction and characteristics of the driving mechanism and its mounting in the crank case, starting with the static absorption of the driving stresses.

The advantages of having the housing cast in the form of a closed block are fully utilized for this purpose. It has a total cross section of very high resistance in all three principal directions. Considering next the vertical assembly of each individual cylinder, the forces exerted by the two cranks of a cylinder are transmitted through the main bearings to the perpen-

dicular partition running through the housing. Each bearing bolt ends in a boss serving as a junction point to which the engine bearers are attached. The transverse stiffness in a horizontal plane is produced by transverse walls which run from the front to the back and are required to separate the crank shaft chamber, the cooling water passages, and the scavenging and exhaust channels. Figure 19 shows the relative position of the crank shafts together with the spur reduction gear.

The construction of the housing in the longitudinal plane was governed entirely by considerations of stiffness and weight. This is taken care of by the proper length of the crank shaft bearings. Therefore, the main bearings are roller bearings, which have proved satisfactory for this purpose. After overcoming certain initial difficulties the spur-gear assembly and its mounting in a light-metal housing also proved satisfactory. The gears were constructed by the gear manufacturing company of Friedrichshafen. The teeth are cut to a high degree of precision and have a very great resistance to wear.

The dynamic characteristics of the driving mechanism require a thorough investigation, especially the torsional vibrations of the shafts. The dangers resulting therefrom in the form of crank-shaft failures in airship and airplane propulsion have been the subject of considerable publicity during the past few years.

To-day we know that it is impossible to keep the large speed

range of an aircraft engine absolutely free from so-called critical vibration periods. It is only possible to keep the amplitude of the vibrations so small that they are no longer dangerous.

The next question is, whether the two-shaft system is more difficult and dangerous with respect to vibrations than the single-shaft system. It can be said that it is more difficult, but not more dangerous. The fact is, it offers more possibility for different forms of vibration, but that, so far as known, its sensitivity and consequently, the amplitude of its vibrations remain harmless (Fig. 20).

The simplest form of vibration, in which the mass system of both crank shafts vibrate together against the large mass of the propeller, can be traced without difficulty by the methods of vibration mechanics, to the well-known single-shaft system. The fundamental form of the vibration can occur with one node, and the upper harmonic with two nodes. Opposing vibrations of the two crank shafts are also possible. These are produced by differences in the rotational forces of the upper and lower crank shafts as occasioned, for instance, by the angular difference between the two shafts necessary for the advanced opening of the exhaust ports.

For determining the amplitude of the vibrations we are still largely dependent on the measurements made on a running engine by means of a torsiograph (Fig. 21), i.e., on experimental investigation. In 1925 a special measuring instrument was devel-

oped for this purpose at the Junkers factory, in connection with the development of a vibration damper for aircraft engines, which is strong and at the same time simple and accurate.

The somewhat complicated measurements on the two-shaft engine with its different forms of vibration necessitated simultaneous measurements of the movement of the upper and lower shaft at the front and rear ends.

Figure 22 shows the free-floating arrangement of the three torsiographs. Figure 23 shows a diagram made by a torsiograph as a polar diagram, first as recorded and then as it was deciphered by a special apparatus. When working at its best and with a minimum inertia of the stylus, the instrument is capable of registering vibrations of very high frequency, as in this particular example, 15,000 per minute.

The adaptation of the engine to aircraft use was accomplished by close cooperation with the Junkers Aircraft Factory. After four years of development work, the first oil engine was recently mounted on an airplane and tested in flight. The engine SL 1 (Fig. 24), was installed and developed a maximum of 650 hp during the first flight test. This was determined by the stroke of the fuel pumps and this power was maintained up to altitudes of 3000 to 3500 m (9800 to 11500 ft.) without experiencing any lack of scavenging. The empty weight of the completed engine, as shown in Fig. 24, is 840 kg (1852 lb.).

The mounting on the airplane (Fig. 25) shows the simple

strut bracing which leads to the engine from the four supporting points on the front frame. The lower engine bearers are eliminated in a later construction, the supporting struts then leading directly to the points of support on the housing. It can also be seen that the fuel pumps and injection nozzles are accessible from both sides of the engine. The arrangements for controlling the engine from the pilot's seat are extremely simple (Fig. 26). Two control levers serve to regulate the engine performance. They can be used either separately or together.

The engine is started by compressed air, likewise controlled by a hand lever from the pilot's seat. The engine starts, even from the cold condition, without any special aid such as ignition cartridges or filling with hot water. No special device is required for eliminating air from the fuel lines and pumps, since the pumps automatically free themselves of air during the first few air-driven revolutions of the engine.

The first flight tests of an engine mounted on a Junkers G 24 airplane took place before the bench tests were completed (Fig. 27). There was urgent need of determining the general characteristics of the new engine as soon as possible, so that the experience gained might be utilized in its further development.

The first short flight of February, 1929, demonstrated that special difficulties with respect to the flight characteristics were no longer to be expected. Quick starting, quiet operation

and good controllability of the engine in flight corroborated all the observations previously made on the test bench.

In reality, these first attempts to fly were not so simple and harmless, for the engine then available for this purpose was no longer new and unused, but had already acquired all sorts of "scars" from the test bench. Besides this it possessed the unavoidable defects of the original design. However, the removal of these defects was simply a question of time and expense.

Altogether about fifty hours of flying has been done for testing the oil engine. The longest continuous flight lasted about 8 hours. The take-off weight of the airplane was usually about 4700 kg (10360 lb.). This corresponds to a power load of 7.5 kg (16.5 lb.) per effective horsepower of the engine.

Translation by
National Advisory Committee
for Aeronautics.

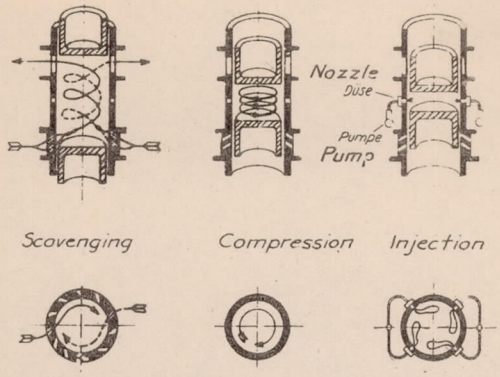


Fig.1 Working process of Junkers eng.

Fig.2 Junkers double-piston engine.(Left) Single-shaft engine. (Right) Two-shaft engine.

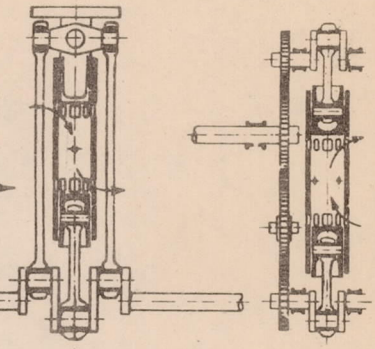
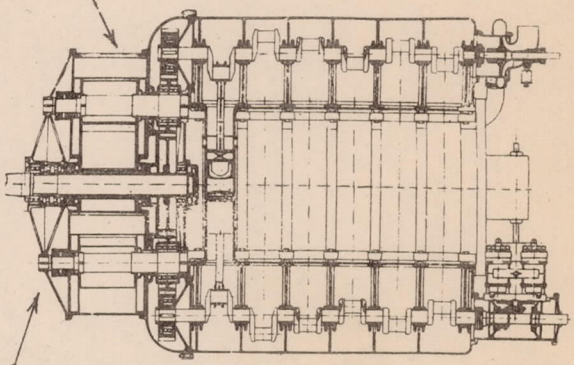


Fig.3 Junkers two-shaft aircraft eng.



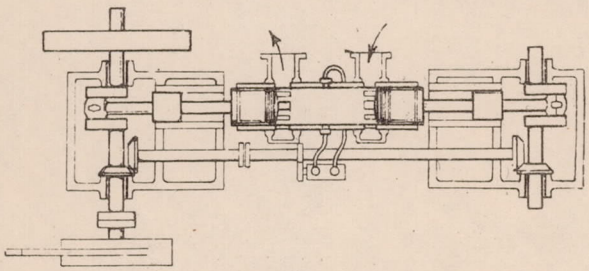


Fig.6 Two-shaft experimental oil eng. "F02" 1916 Benzine-injection, capsule-explosion, 6 cylinder; diam.115 mm stroke 150 mm n 1800, N_e-450 hp Weight 750 kg.

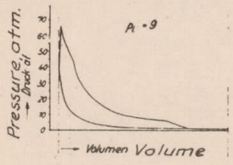
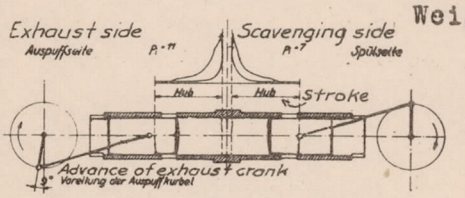


Fig.7 Indicator diagram



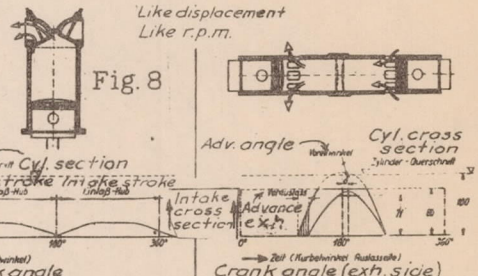
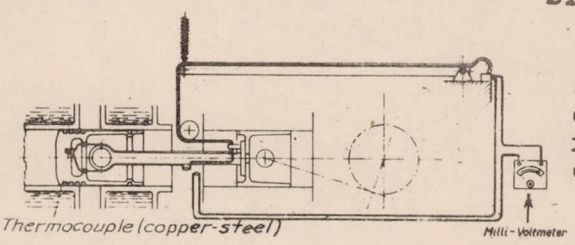
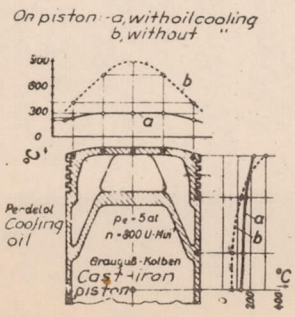


Fig.8 Comparison of characteristics of high-speed Diesel and four-stroke carburetor engine





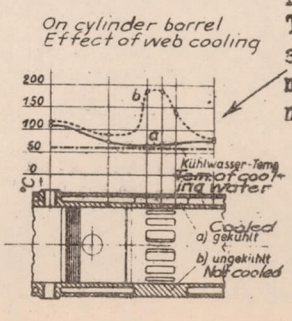


Fig. 18 Temperature measurement.

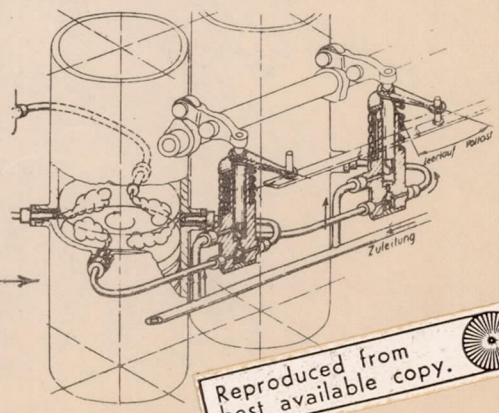


Fig. 12 Fuel injection

Reproduced from best available copy.

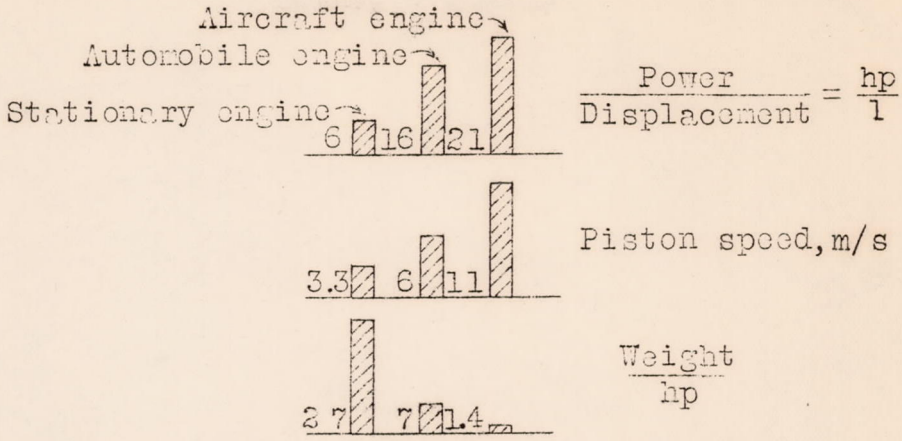


Fig.4 Junkers double-piston engine

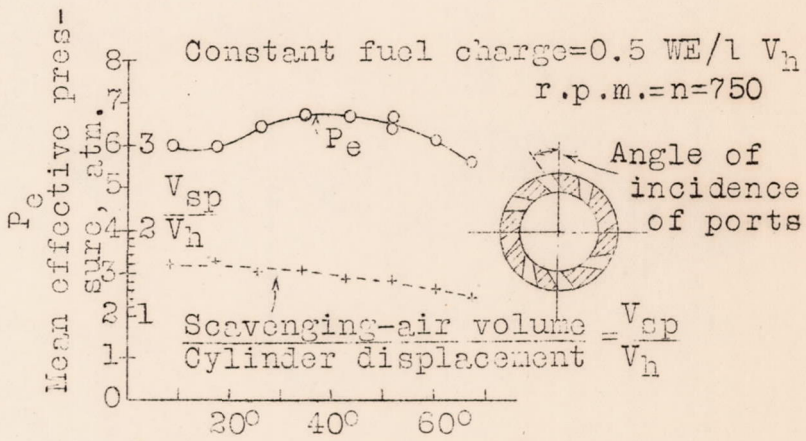


Fig.9 Effect of varying rotation of scavenging air on the combustion.

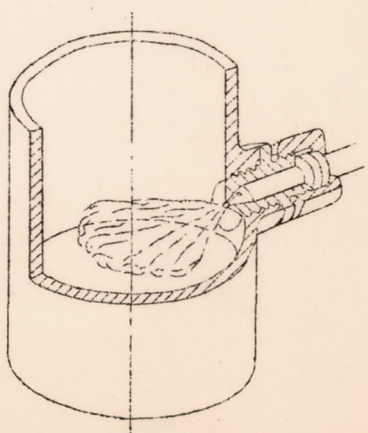


Fig. 10 Junkers nozzle

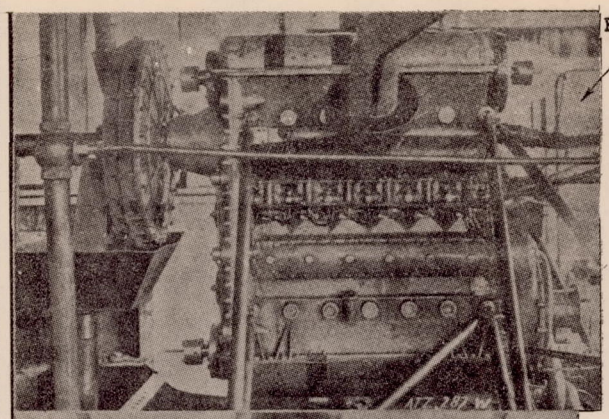


Fig.22 Free-floating arrangement of 3 torsiographs

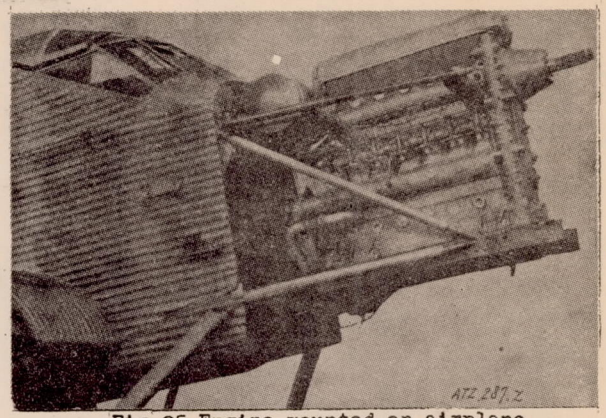


Fig.25 Engine mounted on airplane

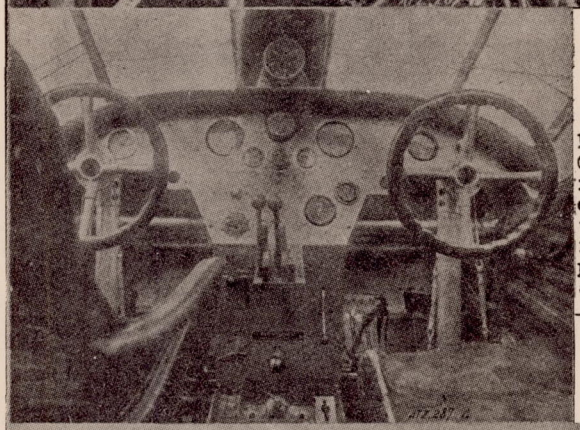


Fig.26 Operating levers of the engine in pilots cockpit

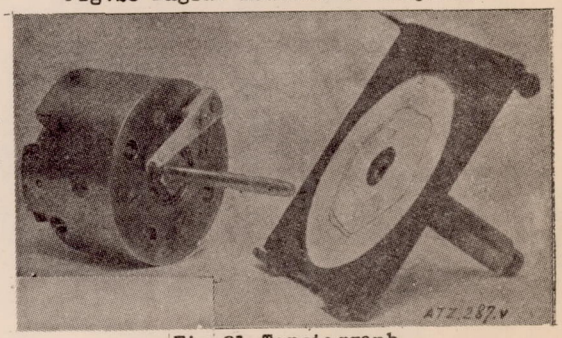


Fig.21 Torsiograph

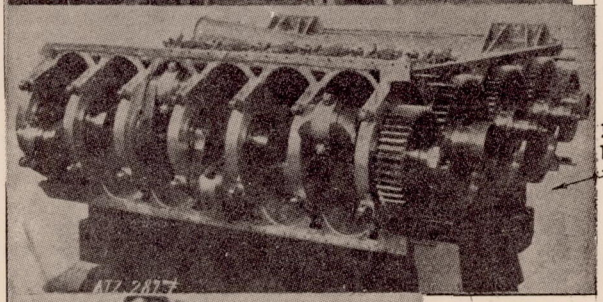


Fig.19 Crank shaft bearings and reduction-gear train

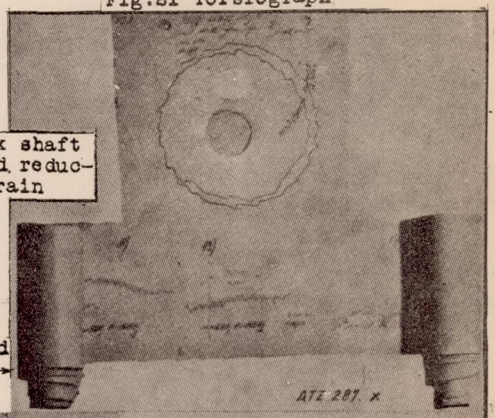


Fig.23 Diagrams recorded by torsiograph

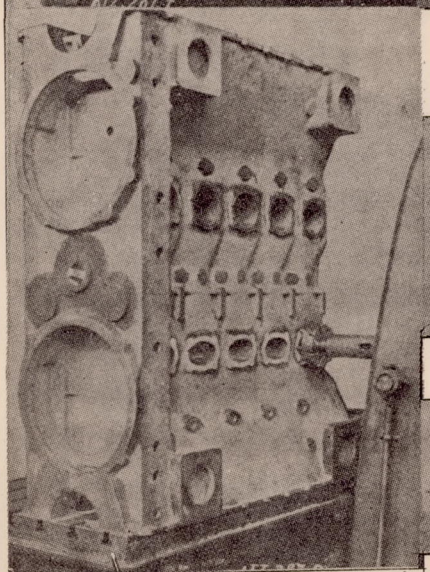


Fig.5 Crankcase and engine housing in one block

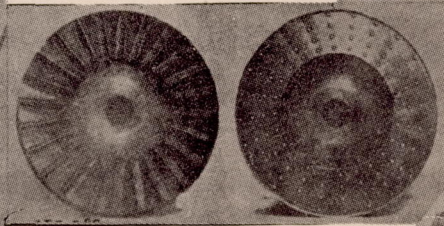


Fig.16 Scavenging-blower rotors

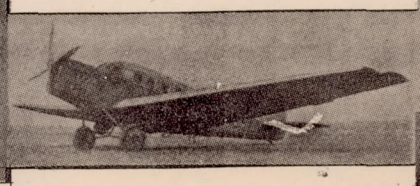


Fig.27 Junkers G24 airplane

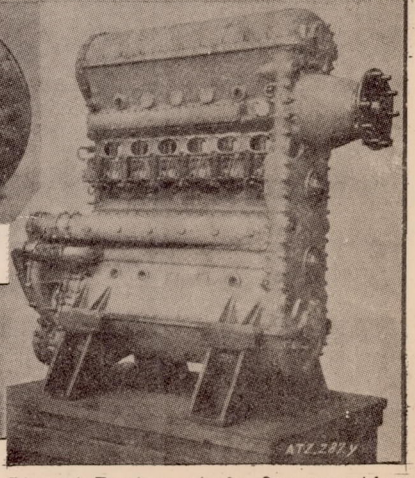
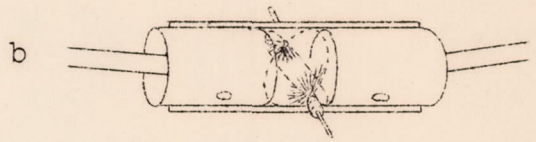


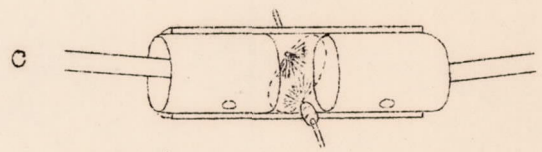
Fig.24 Engine ready for mounting



Both fans in the vertical plane



Fans crossing each other



Both jets in inclines

Fig. 11 Spray arrangement with two nozzles

Reproduced from best available copy.

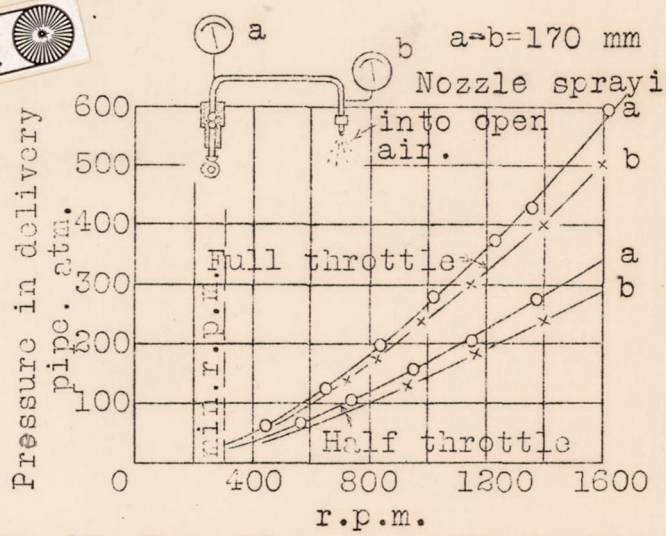


Fig. 13 Injection pressure plotted against r.p.m.

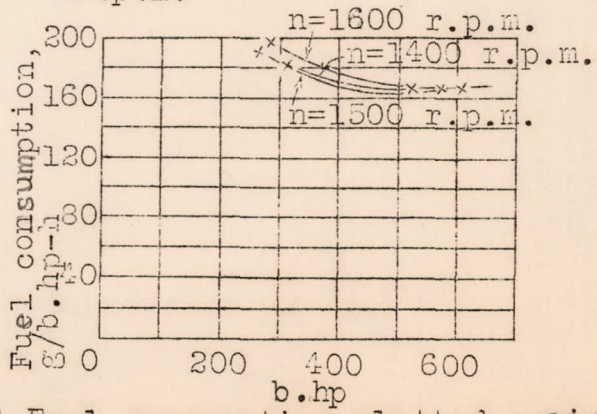


Fig.14 Fuel comsumption plotted against b.hp at different r.p.m.

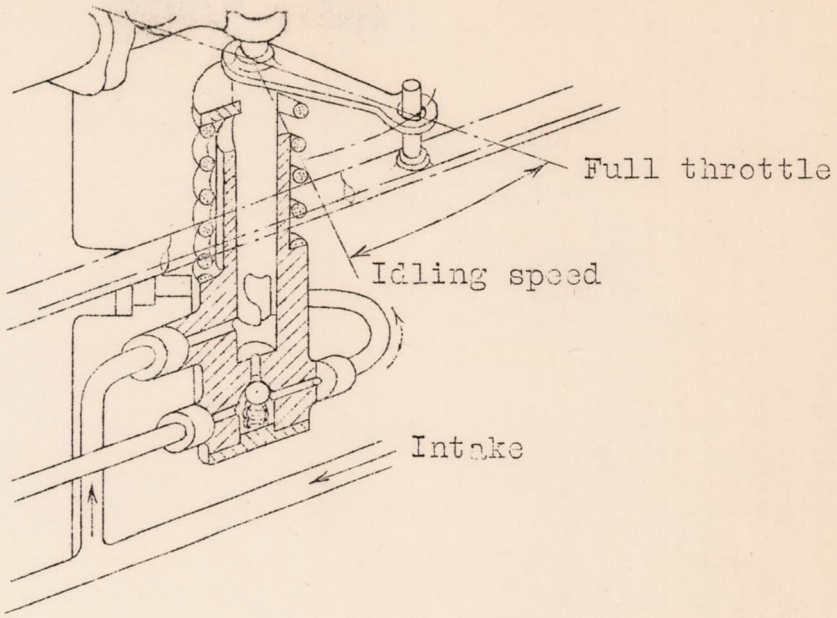


Fig. 15 Section through fuel pump

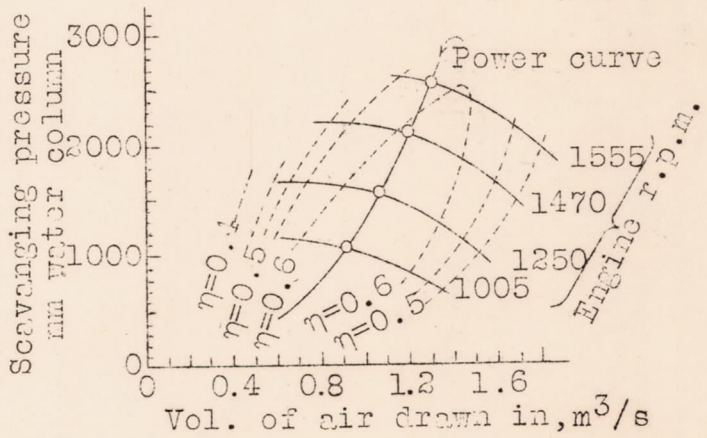


Fig. 17 Characteristic curves of rotary scavenging pump F03.

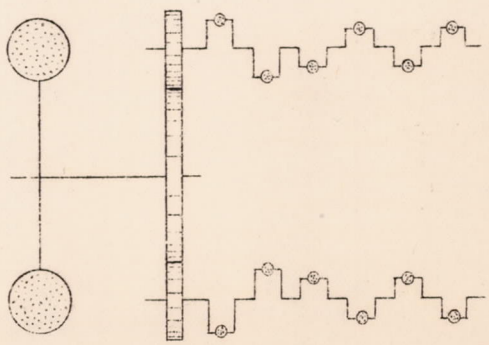


Fig. 20 Inertia system of two shaft engine